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The Use of Lasers in Decontamination of Implant Surfaces and the Treatment of Peri-implantitis – A Mini-Systematic Review

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Abstract:

Introduction: Various implant surface treatments currently available are focusing on decontamination and inhibition of microbial adherence to implant surfaces, thus attempting to prevent peri-implantitis. Laser therapy has shown potential for treating such conditions by safely irradiating titanium surfaces without altering the delicate titanium microstructure, important for osseointegration. The aim of this study was to perform a narrative literature review and analyse current evidence available on the effectiveness of laser decontamination of implant surfaces and treatment of peri-implantitis.

Method: The Electronic databases Medline (via PubMed and OvidSp) and Trip were systematically searched.

Results: Eight studies have been reviewed and treatment outcomes for Er:YAG (Erbium-Doped Yttrium Aluminium Garnet), Carbon Dioxide Lasers (CO₂ lasers), Gallium-aluminium-arsenide (GaAlAs) diode lasers, Nd:YAG (Neodymium-doped yttrium aluminium garnet) and photodynamic therapy have been analysed. Despite inconsistencies among studies in terms of study design, positive short-term therapeutic effects have been observed throughout all investigated studies.

Conclusion: Future research needs to focus on longer follow-up periods, synchronizing user settings by implementing guidance on laser power and application, limiting the use of adjunctive interventions and consistent evaluation of clinical outcome variables throughout studies.

Keywords: Laser Treatment Peri-implantitis

Introduction

A variety of laser settings enables employment in various areas of dentistry. One of them is the rapidly evolving area of implantology. Tissue ablation and reduction in bacterial contamination of implant surfaces, soft tissue management and treatment of peri-implantitis (PI) are of special interest to ultimately improve implant longevity.¹

The most common dental implant failure is due to PI and its incidence ranges from 12%-43% of dental implant sites.² Implant removal rates of 8-50% are also attributable to PI.³ PI can be defined as an inflammatory process affecting peri-implant bone post-osseointegration to the functional implant surface, that ultimately results in bone loss.⁴ Its risk factors include plaque, poor oral hygiene, periodontal disease, diabetes, alcohol consumption and smoking.³

Most commercial dental implants are made of titanium or titanium alloys. To increase surface area and enhance osseointegration, a range of surface modifications are available such as sandblasting, plasma spraying and anodizing etching.³ PI was found to occur more frequently around implants with roughened surfaces as this provides microorganisms with a greater surface area to adhere to.⁵ The formation of biofilms on implant surfaces can induce inflammation and ultimately bone loss.³

Current decontamination protocols suggest plastic curettage, chlorhexidine digluconate, iodine as well as local and systemic antibiotics for titanium surface decontamination. The use of ultrasonics and metal instrumentation is contraindicated due to potential induction of surface alterations of the implant surface.² Using certain lasers with appropriate power settings for debridement, avoids mechanical interference and destruction of the micro-texture of the implant surface.⁶

A variety of lasers for the decontamination of implant surfaces are available. These include Nd:YAG (Neodymium-doped yttrium aluminium garnet), Carbon dioxide (CO₂), Gallium-aluminium-arsenide (GaAlAs) diode, Chromium-doped yttrium-scandium-gallium-garnet and Erbium-doped yttrium–aluminium–garnet (Er:YAG). However, studies found the Er:YAG to be the most consistent.⁷ The Er:YAG laser has proven to be effective in the removal of plaque and calculus on contaminated abutments. This is made possible through emitting a wavelength of 2.94 µm that is highly absorbed in water.⁴ Excellent results in periodontal therapy could be achieved in terms of bactericidal and detoxification effects. These results suggest a potential utilisation of the Er:YAG laser in the removal of biofilms and thus PI therapy.⁴

The aim of this study was to perform a comprehensive literature review of the most relevant papers published on the use of lasers in dental implant surface treatment in patients with PI and to determine its effectiveness of decontamination as well as viability of treating PI.

Materials and Methods

PICO: This is a useful tool for asking a focussed clinical question and is an acronym for: **P**opulation, **I**ntervention, **C**omparison and **O**utcome. In this mini systematic review, our PICO question was: “For patients suffering from peri-implantitis (**P**), is laser decontamination of implant surfaces (**I**), compared to traditional non-surgical periodontal therapy (**C**), an effective method of decontamination and treatment (**O**)?”

Levels of evidence: Not all evidence is equal and systematic reviews consider the quality of evidence before summarising the evidence within a review. This evidence quality is determined by the methods used to reducing bias within a study design. Studies with the

highest levels of evidence quality are randomised controlled trials, followed by at least one randomised controlled trial on the effectiveness of an intervention. Lower levels of evidence are provided by non-randomised controlled trials and single case studies.

Search bases: Electronic databases Medline (via PubMed and OvidSp) and the Trip database were searched by one of the authors (CH) using the following search terms: 'Lasers and Implants', 'Lasers in Implantology', 'Peri-implantitis and Lasers', 'Peri-implantitis and decontamination' and 'Lasers and Biofilm'.

Inclusion criteria:

Literature which examined the effects Laser decontamination in the treatment of peri-implantitis

Literature available through the University of Bristol

Literature from 2000-2014

Literature in the English language

Literature from any country provided that it was available in the English language

Literature which used any study design type

Both primary and secondary source types were considered

Literature was included irrespective of outcome

Exclusion criteria:

There were no further exclusion criteria were applied due to the limited number of publications in this field.

PRISMA flow diagram: A PRISMA flow diagram of the papers selected for review is shown in Figure 1. Forty papers were initially identified and the titles and abstracts of each paper were read by a single author (CH). Thirty-four papers were rejected based on their irrelevance to this review. Bibliographies of these forty papers were also searched for relevant articles and this resulted in two more publications being deemed suitable. Thus, a total of eight articles, published between 2005 and 2014 were selected for analysis (Table 1).

Data capture: Full-text analysis of all included articles was carried out and information was extracted for assessment using data capture sheets which recorded the following data:

a) Primary research studies:

- Study, Year
- Type of study
- Laser investigated
- Control
- Type of Implants
- No. of Implants/No. of patients
- Surgical/Non – surgical intervention
- Adjunctive therapeutics - test and control groups
- Follow up period
- BOP
- Plaque index
- Clinical attachment level (CAL)
- Pocket probing depth (PPD)
- Gingival recession
- Bone levels

- Wavelength
- Tip
- Tip movement
- Tip angulation
- Mode
- Pulse duration
- Power
- Time of application

b) Review papers:

- Publication, Year and laser investigated
- Inclusion/Exclusion criteria
- Studies included in review
- Type of studies
- Clinical outcomes/Decontamination potential

The completed data capture sheets are shown in Tables 2 to 4.

Bias: A summary of the risk of bias for all studies included within this review , based upon the Cochrane Collaboration's tool,⁸ is shown in Table 5.

Results

The eight studies selected for review included one Case Report,¹ one Histological Study,⁴ one Clinical Follow-up,⁹ one Pilot Study,¹⁰ two Randomised Control Trials (RCTs),^{11,12} one Narrative Review,¹³ and one Systematic Review and Meta-Analysis.⁷

Primary research papers analysed five Er:YAG lasers and one Diode laser and collected data on clinical variables such as bleeding on probing (BOP), plaque index, pocket probing depth (PPD), clinical attachment levels (CAL), gingival recession and bone levels. The reviews assessed decontamination efficacy of five different lasers and in total investigated eleven Er:YAG lasers, seven CO2 lasers, three Nd:YAG lasers, seven GaAlAs diode lasers and one Photodynamic treatment (HELBO).

Laser therapy in peri-implantitis treatment: Primary research mostly utilised Er:YAG lasers either as a monotherapy^{10,12} or adjunctive intervention^{2,4,8} in the treatment of peri-implantitis, whilst only one study attempted to observe the efficacy of a Diode laser.¹¹ A total number of 175 implants, with a range of different titanium surfaces, were irradiated to measure clinical outcomes. All studies collected their final data after 6 months post-intervention, apart from one study⁸ where the last follow up was scheduled at 24 months.

Adjunctive treatment: In most studies^{4,9,10} plastic curettage was used as a control whilst one study¹¹ utilised air-abrasive therapy. Peri- and post-operative medicament adjuncts were used within the control groups, including post-surgery antibiotics⁴ and chlorhexidine digluconate 0.2% solution and 0.2% gel.¹⁰ One study⁹ used natural bone mineral and collagen membranes within the control group. Additionally, a PERIO-FLOW device was utilised in one study.¹²

Whilst one study¹⁰ did not use any adjunctive therapeutics for the laser test group, one utilised the same post-surgery antibiotics as in their control group⁴ but with the addition of 2% chlorhexidine gluconate solution whilst two studies^{9,11} used the same adjuncts for their test and control group.

Surgical versus non-surgical intervention: Two studies^{4,11} used flap surgery for subgingival access, whilst another⁹ also used a surgical approach but in conjunction with implantoplasty.

A two-stage treatment protocol was implemented in one study² whereby stage 1 was non-surgical and stage 2 surgical. Two studies^{10,12} used a non-surgical approach for decontamination.

Laser power settings: Er:YAG power settings varied between studies, whilst some papers did not report on certain variables. Only two studies^{4,10} used a wavelength of 2.94 µm in contact mode. More similarly, two studies^{10,12} applied a cone-shaped tip with circular tip movement, parallel tip angulation and power at 100mJ/pulse but one¹² did not report on wavelength and pulse duration. One study² only reported the type of tip, tip movement, angulation and power used, making it more difficult to compare to other studies.

Power settings for the diode laser utilized in one study¹¹ only reported on wavelength, mode, power settings and time of application. Only one other study also reported on irradiation time.²

Effects of Er:YAG on BOP: One study² reported no bleeding after 3 months of laser treatment, whilst another¹² observed this in only 31% of cases after 6 months post laser therapy. The remaining three studies recorded a statistically significant reduction in BOP, whilst one study⁴ did not investigate this clinical variable.

Effects of Er:YAG on plaque index: Three studies^{9,10,12} recorded non-significant changes in plaque levels without significant differences between groups. Two studies^{2,4} did not report on this outcome variable.

Effects of Er:YAG on CAL: Only two studies by Schwartz *et al.*^{9,10} reported on clinical attachment levels. The 2012 study⁹ observed a statistically significant reduction in mean CAL values in both groups at 12 months but failed to reach statistical significance after 24 months. Between-group comparisons were of no significance. The 2005 study¹⁰ however, observed a

statistically significant CAL gain but inter-group comparison did not reach clinical or statistical significance.

Effects of Er:YAG on PPD: Four studies reported significant reductions in pocket probing depths, whilst one study⁴ did not record this variable. One study² observed a significant reduction in PPD after both, stage 1 (non-surgical) and stage 2 (surgical) treatment. Although, one study⁹ reported a significant improvement after 12 months with no notable differences between groups, at 24 months, only the control group remained significant. Compared to other studies, one study¹⁰ observed differences in post- treatment and baseline pocket depths, by categorising the pockets into shallow, moderate or deep pockets. Initially deep pockets showed significant changes in PPD, whilst moderate pockets showed moderate improvements and shallow sites exhibited statistically non-significant changes. One study¹² observed reductions in PPD in both groups but the overall clinical improvement was limited.

Effects of Er:YAG on gingival recession: Three studies reported mild gingival recession^{2,9,10} whilst two studies^{4,12} did not report on this outcome.

Effects of Er:YAG on bone levels: The main outcome measures in one study⁴ was new bone formation, collecting data on new bone height (NBH) and new bone-to-implant contact (NBIC), by using light microscopy and histometrical analysis. An increase in NBH and NBIC were observed in the laser group compared to the curette control group. However, the difference between groups did not reach statistical significance.

Only two studies^{2,9} adjunctively utilised synthetic or natural bone. One of these² reported bony infill of defects via radiographic evaluation, 6 months after surgery, and no further investigations were carried out in light of laser efficacy and new bone formation in this study. The other⁹ also observed an initial increase in bone levels after 12 months but this slightly decreased after 24 months.

Whilst three studies reported some degree of increased bone levels, one study¹² was the only paper observing a loss in bone levels after 6 months, although not clinically significant. One study¹⁰ did not report on bone levels.

Effects of diode laser on clinical outcomes: One study¹¹ reported a significant reduction in BOP at 3 and 6 months after treatment, with no statistically significant difference between groups. Plaque levels saw a continuous reduction between baseline, 3 and 6 months post irradiation. Further statistically significant reductions were observed for CAL at both follow up time points. PPD showed no statistical difference at 3 and 6 months between groups. PPD was decreased at both re-examinations but the second visit did not show any further statistically significant improvements.

Review of clinical outcomes following Er:YAG, CO₂ and photodynamic therapy: The review study¹³ observed similar clinical outcomes for CO₂ lasers as with Er:YAG lasers, however Photodynamic therapy did not reach statistical significance for CAL and PPD was of no clinical significance.

Review of decontamination efficacy following Er:YAG, CO₂, GaAlAs diode, Nd:YAG laser therapy: One study⁷ reviewed the decontamination potentials and bactericidal efficacies using various laser systems. All lasers exhibited dose dependant decontamination potentials. CO₂ lasers required higher settings to achieve 100% decontamination compared to Er:YAG. However, GaAlAs diode lasers reached near complete elimination of microbes at only 2.5W - half of that required for Er:YAG lasers.

Meta-analysis for Er:YAG laser treatment at the 6-month post-intervention observational interval: Outcome measures were deemed to be heterogenic enough to evaluate mean outcomes of CAL and PPD by including 3 surgical studies and 1 non-surgical study. Results revealed no statistical significance of CA loss after 6 months for the surgical and non-surgical

group and for all studies. Similarly, PPD was also found to be non-significant for surgical and non-surgical groups and all studies respectively. No evidence for subgroup differences between non-surgical and surgical interventions in CA loss and PPD reduction treatments were identified.

Discussion

The basis of successful treatment of PI disease is a healthy periodontium that requires excellent patient education on oral hygiene, constant re-enforcement and motivation. Thus, patient compliance is vital after decontamination. Despite that, some studies failed to record plaque levels, leading to inconsistencies in results. One study¹¹ reported a decrease in plaque levels post-laser treatment, however, this kind of outcome may be confounded by patient's improved oral hygiene regime. It is therefore hard to evaluate whether this was down to laser efficacy or patient factors. Regular follow up visits to monitor and maintain oral hygiene is of paramount importance. The serious confounding factor of smoking was ignored by all but one study¹² and did not feature in the exclusion criteria. Furthermore, patient's medical history including systemic disease and medications that could potentially interfere with healing or osseointegration, were not taken into consideration either. Only one study¹² recorded the differences in smoking years and medications between participants but did not exclude subjects on the basis of these variables.

The study designs varied widely, including the use of different surgical and non-surgical treatments with the addition of adjunctive therapies between studies as well as within test- and control groups. This further complicates the comparison of outcome variables, hence relative laser efficacy assessments cannot be made. Not all studies recorded the same clinical parameters, including p-values, making a reliable inference impossible.

Small sample sizes in some studies might be skewing outcome data and statistical significance cannot be obtained. Power calculations to estimate an acceptable number of patients and/or implants needed to obtain a positive therapeutic outcome are required.

Potential operator bias could not specifically be identified but most studies did not mention the number of operators or their skill level, causing possible inter-study discrepancies.

Most studies selected to treat acute PI, but no universal definition was used throughout the studies, potentially shifting some outcomes to look more favourable compared to others. Although, some studies reported on suppuration, this was not a consistently reported variable.

One of the biggest inconsistencies between studies was noted in terms of laser settings and application. Whilst some variables were left unreported, others varied widely, in spite of research showing that energy levels have a significant effect on decontamination of implant surfaces.⁷ Future research needs to address the implementation of protocols and guidance for laser application to enable evaluation of the relative effectiveness of lasers on implant decontamination and safety. This will become particularly important with the introduction of new high pulse repetition rates, increasing the risk of thermally altering the implant surface morphology.⁴ Thus, some current lasers are deemed unsuitable for implant decontamination due to reports of cracking, crater formation and melting of titanium surfaces following the use of Nd:YAG and holmium-doped:YAG lasers. CO₂ lasers are commonly used to irradiate implant surfaces, however, there is increased risk of heating the titanium implant and surrounding bone.^{14,15} One study¹⁶ investigated the Er:YAG laser for visible irradiation damage and reported no changes of titanium under 50 mJ/pulse (energy density 17.7 J/cm²) and constant water spray using contact mode. Furthermore, a second study¹⁷ investigated microstructural changes when irradiation parameters were set to 12.7 J/cm² and 10 Hz

energy density, whilst cooling the implant surface with water, but no alterations in surface structure could be observed either. Thus, research accepts the safe use of Er:YAG laser systems for implant surface decontamination.

A 2008 Cochrane systematic review concluded that only very little reliable evidence currently formulates an effective intervention for treating PI, further confirming the need for future research, including laser therapy.¹⁸

Conclusions

The research question “For patients suffering from peri-implantitis, is laser decontamination of implant surfaces, compared to traditional non-surgical periodontal therapy, an effective method of decontamination and treatment?” has not been answered by this mini-systematic review. The use of lasers in dental implant surface treatment requires further high quality RCTs to be undertaken and would greatly benefit from prioritising the implementation of standards for laser parameters and applications. Most studies focused on Er:YAG lasers, but it would be interesting to see future research investigating more treatment outcomes of CO₂ and Diode laser therapies. The use of adjuncts needs to be limited to evaluate true laser efficacy. Detailed patient selection, Plaque indices and severity of PI needs to be uniformly reported throughout research papers as well as the same outcome variables to allow comparison. Positive outcome measures have been obtained after 6 months, suggesting an effective initial response to laser decontamination, however, results generally tailed off at 24 months in the one study that obtained records at this time point. Hence, re-examinations up

to at least one year following treatment with intermittent visits for general implant maintenance, oral hygiene and vital patient motivation, need implementing.

Based on the limited amount of information available, the implications for clinicians at this point in time is to follow manufacturers recommended laser settings, whilst using their clinical expertise and judgement when carrying out laser therapy in patients with PI.

Conflicts of Interest:

The authors have no conflicts of interest.

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Table 1: The studies included within this review

Study	Type of study	Laser type	Control	Follow up period
Badran et al., 2011	Case report	Er:YAG	N/a	3 and 6 months
Takasaki et al., 2006	Histological study	Er:YAG	Plastic curettes	24 weeks
Schwarz et al., 2012	Clinical follow up	Er:YAG	Plastic curettes	12 and 24 months
Schwarz et al., 2005	Pilot study	Er:YAG	Plastic curettes and chlorhexidine digluconate 0.2%	3 and 6 months
Papadopoulos et al., 2014	RCT	Diode laser	Plastic curettes	3 and 6 months

Renvert et al., 2011	RCT	Er:YAG	Air-abrasive therapy	6 months
Kotsakis et al., 2014	Systematic Review	<ul style="list-style-type: none"> - CO₂ laser - Er:YAG - Photodynamic treatment (HELBO) 	-	-
Kamel et al., 2014	Narrative Review	<ul style="list-style-type: none"> - GaAlAs diode - CO₂ - Nd:YAG - Er:YAG 	-	-

Figure 1: PRISMA flow diagram of the studies included within the review

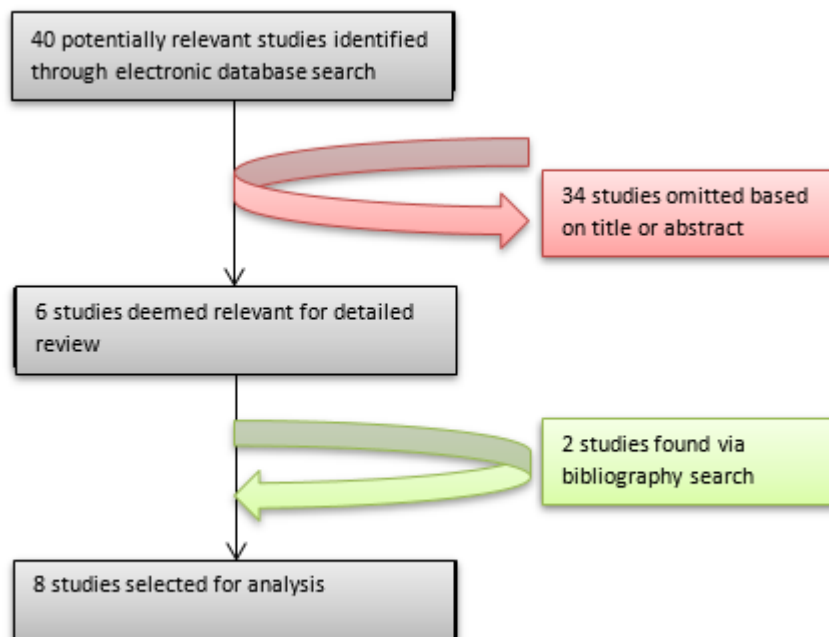


Table 2: Characteristics of included primary research studies

Study	Type of study	Laser type	Control	Type of implant	No. of implants/no. of patients	Surgical/Non-surgical intervention	Adjunctive therapeutics for test group	Adjunctive therapeutics for control group	Follow up period	Comments
Badran et al., 2011	Case report	Er:YAG	N/a	Not reported	1 implant/1 patient	Stage 1: non-surgical; Stage2: surgical	Surgical ultrasonic debridement; bone cures, synthetic bone substitute (BCP)	N/a	3 and 6 months	
Takasaki et al., 2006	Histological study	Er:YAG	Plastic cures	Sand-blasted large grit acid-etched (SLA) surface implants (solid screw \varnothing 3.3 x 10 mm standard plus, ITI® Dental implant system, Straumann AG, Waldenburg, Switzerland	16 implants/Four 1-year-old beagle dogs	Peri-implant flap surgery	2% Solution of Chlorhexidine gluconate; Antibiotics for 3 days post-surgery	Saline solution irrigation; Antibiotics for 3 days post-surgery	24 weeks	Increase in new bone height and new bone-to-implant contact, compared to the control group, although not statistically significant
Schwarz et al., 2012	Clinical follow up	Er:YAG	Plastic cures	Implant systems: ANK, AST, BRA, CAM, ITI, KSI, REP, TSV, XIV, NI*;	26 implants/24 patients	Flap surgery; Implantoplasty	Natural bone mineral and collagen membrane	cotton pellets; sterile saline; natural bone mineral and covered with a collagen membrane	12 and 24 months	Reductions of BOP, PPD and CAL were significant at 12 months, however, only the reduction in BOP remained significant after 24 months
Schwarz et al., 2005	Pilot study	Er:YAG	Plastic cures and chlorhexidine digluconate 0.2%	Titanium implants (Straumann) Screw type; SLA; TPS	32 implants/20 patients	Non-surgical	No adjuncts used	chlorhexidine digluconate 0.2%; subgingival application of CHX gel 0.2 %	3 and 6 months	Reductions of BOP, PPD and CAL were significant, despite unchanged plaque levels
Papadopoulos et al., 2014	RCT	Diode laser	Plastic cures	Titanium Implants	16 implants/16 patients	Flap surgery	Plastic cures, sterilized gauzes soaked in saline	Plastic cures, sterilized gauzes soaked in saline	3 and 6 months	Reductions in BOP, PPD and CAL 6 months after treatment; However, diode laser irradiation did not deem to add any additional benefits clinically
Renvert et al., 2011	RCT	Er:YAG	Air-abrasive therapy	Not reported	100 implants/42 patients	Non-surgical	No adjuncts used	PERIO-FLOW® device	6 months	Reduction of BOP was significant, however, reduction in PPD was not

*ANK=Ankylos® (cylindrical screw, microrough surface), Dentsply Friadent, Mannheim Germany; AST=Astra Dental Implant System® (cylindrical screw, microthread, nanotype surface), Astra Tech Dental, Moelndal, Sweden; BRA=Branemark System® (cylindrical screw, machined surface), Nobel Biocare AB, Goeteborg, Sweden; CAM=Camlog Screw Line® (cylindrical screw, microrough surface), Camlog Biotechnologies AG, Basel, Switzerland; ITI,ITI® (cylindrical screw, microrough surface), Institute Straumann AG, Basel, Switzerland; KSI= KSI Bauer Schraube® (conical screw, machined surface), KSI GmbH, Bad Nauheim, Germany; REP=NobelReplace® (tapered screw, microrough surface), Nobel Biocare AB, Goeteborg, Sweden; TSV=Tapered Screw Vent® (tapered screw, microrough surface), Zimmer Dental, Freiburg, Germany; XIV=Xive® (cylindrical screw, microrough surface), Dentsply Friadent, Mannheim, Germany; NI=Non-identifiable implant systems.

Table 3: Laser settings and applications used in included primary research studies

<i>Study</i>	<i>Laser type</i>	<i>Wavelength</i>	<i>Tip</i>	<i>Tip movement</i>	<i>Tip angulation</i>	<i>Mode</i>	<i>Pulse duration</i>	<i>Power</i>	<i>Time of application</i>
<i>Badran et al., 2011</i>	<i>Er:YAG</i>	<i>Not reported</i>	<i>Bevelled</i>	<i>Not reported</i>	<i>10 - 15 degrees</i>	<i>Not reported</i>	<i>Not reported</i>	<i>120 mJ; frequency, 10Hz</i>	<i>Irradiated for 60 seconds</i>
<i>Takasaki et al., 2006</i>	<i>Er:YAG</i>	<i>2.94 μm</i>	<i>Chisel sapphire glass (P/N 625-8746) with rectangular pointed head of 1.40 x 0.45 mm</i>	<i>Scraping motion</i>	<i>30 - 45 degrees, oblique to implant surface</i>	<i>Contact</i>	<i>30 pps</i>	<i>10.0 J/cm² (62 mJ/pulse); frequency 20 Hz</i>	<i>Not reported</i>
<i>Schwarz et al., 2012</i>	<i>Er:YAG</i>	<i>Not reported</i>	<i>Not reported</i>	<i>Not reported</i>	<i>Not reported</i>	<i>Not reported</i>	<i>Not reported</i>	<i>11.4 J/cm², frequency 10 Hz</i>	<i>Not reported</i>
<i>Schwarz et al., 2005</i>	<i>Er:YAG</i>	<i>2.94 μm</i>	<i>Cone-shaped glass fibre</i>	<i>Circular motion from coronal to apical</i>	<i>Parallel to implant</i>	<i>Contact</i>	<i>10 pps</i>	<i>12.7 J/cm² (100mJ/pulse); 85 mJ/pulse</i>	<i>Not reported</i>
<i>Papadopoulos et al., 2014</i>	<i>Diode laser</i>	<i>980 nm</i>	<i>Not reported</i>	<i>Not reported</i>	<i>Not reported</i>	<i>Pulsed</i>	<i>Not reported</i>	<i>0.8 W;</i>	<i>Surface irradiated 3 times with 2 min. intervals</i>
<i>Renvert et al., 2011</i>	<i>Er:YAG</i>	<i>Not reported</i>	<i>Cone-shaped sapphire</i>	<i>Semi-circular motion around the circumferential pocket area</i>	<i>Parallel to implant</i>	<i>Parallel</i>	<i>Not reported</i>	<i>12.71 J/cm² (100mJ/pulse)</i>	<i>Not reported</i>

Table 4: Outcome measures recorded in included primary research studies

Study	Type of study	Laser type	BOP	Plaque index	Clinical attachment level	Pocket probing depth	Gingival recession	Bone levels
Badran et al., 2011	Case report	Er:YAG	No bleeding after 3 months	Not reported	Not reported	Baseline: 5 -9 mm; Reduction after 3 months: PPD 2-5 mm, following non-surgical treatment; Additional reduction after 6 months: PPD 0 - 2 mm post-augmentation	Increased by 1 - 2 mm	Bony infill
Takasaki et al., 2006	Histological study	Er:YAG	Not reported	Not reported	Not reported	Not reported	Not reported	61.8 ± 32.7 and 69.7 ± 15.2% New bone height and new bone-to-implant contact (mean ±SD, n =4)
Schwarz et al., 2012	Clinical follow up	Er:YAG	Reduction after 12 months: 55.0 ± 28.4%; Reduction after 24 months: 75.0 ± 32.6%	Non-significant reduction after 12 months of 0.42 ± 1.0 and 0.2 ± 0.6 (mean ± SD) after 24 months. No significant difference btw. groups (p >0.05)	Reduced after 12 months: 1.3 ± 1.2 mm; Reduction after 24 months: 1.0 ± 2.2 mm	Reduction after 12 months: 1.7 ± 1.2 mm; Reduction after 24 months: 1.1 ± 2.2 mm	Increased after 12 months by 0.4 ± 0.2 mm; Slight decreases after 24 months: 0.1 ± 0.4 mm	Initially 1 - 3 mm gain in 80% of patients, followed by slight loss after 24 months
Schwarz et al., 2005	Pilot study	Er:YAG	30% after 3 months; 31% after 6 months compared to 83% at baseline	Non-significant reduction after 3 months from 1.1 ± 0.5 (baseline) to 1.0 ± 0.6 follow by a slight increase after 6 months to 1.1 ± 0.4	Mean gain after 6 months of 0.6 ± 0.3 mm in moderately deep sites; in deep sites 0.9 ± 0.5 mm; shallow sites non-significant	Reduction after 3 months and 6 months of 0.8 ± 0.1 mm;	Non-significant increase after 3 and 6 months of 0.1 ± 0.1 mm	Not reported
Papadopoulos et al., 2014	RCT	Diode laser	Significant reduction at 3 and 6 months	4.2% reduction of plaque levels after 3 months with additional reduction of 5.4% after 6 months	Reduction of 0.71 mm after 3 months, with a further reduction of 0.8 mm after 6 months.	Reduction after 3 months of 1.38 mm; Reduction after 6 months of 1.48 mm	Not reported	Not reported
Renvert et al., 2011	RCT	Er:YAG	No evidence of bleeding in 31% of implants treated after 6 months	Non-significant changes in visible plaque between groups at 6 and 12 weeks and 6 months; Slight reduction after 6 months in control group (p <0.05)	Not reported	Reduction of 0.8 mm (SD ± 0.5) after 6 months with a reduction of > 1.0 mm in 25% of subjects	Not reported	Reduction of 0.3 mm (SD + 0.9) after 6 months

Table 4: Included review articles and their corresponding publications, laser investigations and overall findings

Review article	Type of review	Lasers investigated	No. of studies included	Inclusion criteria/Exclusion criteria	Studies included in review	Lasers investigated	Type of study	Comments
Kotsakis et al., 2014	Systematic Review; Meta-analysis	Er:YAG; CO ₂ laser; Photodynamic therapy	6	<u>Inclusion criteria:</u> - English language Human studies - Prospective, controlled, clinical studies reporting data from at least 10 patients - Use of Laser therapy as monotherapy or as an adjunct in the treatment of peri-implantitis - Report of clinical indexes of peri-implant disease, including CAL and PD - Follow-up of at least 6-months following treatment <u>Exclusion criteria:</u> - Not stated	Deppe et al., 2007	Carbon dioxide laser	Prospective clinical study	- Significant reduction in PD; CAL only significantly reduced in conjunction with adjunctive bone augmentation; - Halting CAL was significantly more successful, compared to conventional treatment, when combined with soft tissue resection
					Schwarz et al., 2012	Er:YAG	RCT	- Statistically significant reduction in PD at 12 months but not significant after 24 months; - BOP and CAL significantly reduced at 12 months, however, only BOP remained significant after 24 months
					Renvert et al., 2011	Er:YAG	RCT	- No significant reduction in PD but a significant reduction in BOP, 6 months post-treatment
					Schwarz et al., 2006	Er:YAG	RCT	- Significant reduction in CAL and PD, 6 months post-treatment but the reduction is not maintained after 12 months (mean reduction in PD and CAL: <1mm) - Reduction in BOP was significantly greater compared to baseline
					Schwarz et al., 2005	Er:YAG	RCT	- Same findings as Schwarz et al., 2006
					Schaer et al., 2013	Photodynamic treatment (HELBO)	RCT	- Reduction in CAL was statistically not significant; Significant reductions in PD after 6 months, but magnitude of reduction was of no clinical significance (0.36mm)

Table 4 (continued)

Review article	Type of review	Lasers investigated	No. of studies included	Inclusion criteria/Exclusion criteria	Studies included in review	Lasers investigated	Type of study	Comments
Kamel et al., 2014	Narrative Review	Nd:YAG; Er:YAG; CO ₂ and Diode lasers	18	<u>Inclusion criteria:</u> <ul style="list-style-type: none"> - English language - Published within the past 20 years, current to 8 February 2012 <u>Exclusion criteria:</u> <ul style="list-style-type: none"> - Clinical studies - Case reports - Case series - Animal studies - Review articles 	Goncalves et al., 2010 Haas et al., 1997 Kato et al., 1998 Mouhyi et al., 1998 Mouhyi et al., 2000 Kreislner et al., 2002 Kreislner et al., 2003 Matsuyama et al., 2003 Shibli et al., 2004 Schwarz et al., 2005 	GaAlAs diode laser; Nd:YAG GaAlAs diode laser Carbon dioxide laser Carbon dioxide laser Carbon dioxide laser Er:YAG GaAlAs diode laser Er:YAG Carbon dioxide laser Er:YAG Nd:YAG	All in vitro studies	<p><u>Decontamination potentials:</u></p> <p><u>Er:YAG:</u></p> <ul style="list-style-type: none"> - Er:YAG exhibited dose-dependent decontamination, ranging from 59% following irradiation with 80 mJ/pulse at 5 Hz (Tosun et al., 2012) to 99.94% with 120 mJ/pulse at 10 Hz (Kreislner et al., 2002); - Increased decontamination was observed in very short pulse (VSP) mode at any given power, compared to short pulse (SP) mode. - However, 100% decontamination could only be consistently achieved at 90 mJ/pulse at 10 Hz in SP mode (Tosun et al., 2012). <p><u>Carbon dioxide laser:</u></p> <ul style="list-style-type: none"> - CO₂ lasers exhibited a dose-dependent bactericidal efficacy with values ranging from 68% with 2-4 W (10 ms/pulse, 20 Hz) to 100% with 6 W (20 ms/pulse, 20 Hz) (Tosun et al., 2012). - Streptococcus sanguinis shows greater irradiation resistance than Porphyromonas gingivalis when exposed to 15 to 40 J (Kato et al., 1998); (Hauser-Gerspach et al., 2010). <p><u>GaAlAs diode laser:</u></p> <ul style="list-style-type: none"> - Dose-dependent decontamination efficacy with decontamination of 45% at 0.5 W to 99.9% at 2.5 W (Kreislner et al., 2003) - Some studies reported that 100% decontamination cannot be achieved (Kreislner et al., 2003); (Sennhenn-Kirchner et al., 2007); others reported 100% decontamination at powers as low as 1 W (Tosun et al., 2012) and bacterial reductions ranging between 94.67 and 100% (Sennhenn-Kirchner et al., 2007). Enterococcus faecalis and S. sanguinis exhibited increased irradiation resistance to GaAlAs diode lasers, compared to P. gingivalis (Goncalves et al., 2010); (Hauser-Gerspach et al., 2010). <p><u>Nd:YAG laser:</u></p> <ul style="list-style-type: none"> - Powers ranging from 0.3 to 3.0 W exhibited incomplete elimination of microbes in some studies (Giannini et al., 2006); (Block et al., 1992); others showed 100% decontamination using 3.0 W (Goncalves et al., 2010). - P. gingivalis was easier to eliminate compared to E. faecalis (Goncalves et al., 2010).

					<i>Giannini et al., 2006</i>			
					<i>Schwarz et al., 2006</i>	<i>Er:YAG</i>		
					<i>Quaranta et al., 2009</i>	<i>Er:YAG</i>		
					<i>Sennhenn- Kirchner et al., 2009</i>	<i>Er:YAG; GaAlAs diode laser</i>		
					<i>Tosun et al., 2012</i>	<i>Er:YAG; Carbon dioxide laser; GaAlAs diode laser</i>		
					<i>Block et al., 1992</i>	<i>Nd:YAG</i>		
					<i>Hauser-Gerspach et al., 2010</i>	<i>Carbon dioxide laser; GaAlAs diode laser</i>		
					<i>Sennhenn- Kirchner et al., 2007</i>	<i>GaAlAs diode laser</i>		

Table 5: Summary of risk of bias within the included studies, based upon the Cochrane Collaboration's tool.⁵

Study	Type of study							
Badran et al., 2011	Case report	N/a	N/a	N/a	N/a	N/a	N/a	High
Takasaki et al., 2006	Histological study	N/a	N/a	N/a	N/a	N/a	N/a	High
Schwarz et al., 2012	Clinical follow up	N/a	N/a	N/a	N/a	N/a	N/a	High
Schwarz et al., 2005	Pilot study	N/a	N/a	N/a	N/a	N/a	N/a	High
Papadopoulos et al., 2014	RCT	Low	Unclear	Low	Unclear	High	Unclear	Unclear
Renvert et al., 2011	RCT	Low	Unclear	Low	Unclear	Low	Low	Unclear
Kotsakis et al., 2014	Systematic Review	N/a	N/a	N/a	N/a	N/a	N/a	Low
Kamel et al., 2014	Narrative Review	N/a	N/a	N/a	N/a	N/a	N/a	Low
		Random Sequence Generation	Allocation Concealment	Blinding of Participants and Personnel	Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Reporting	Other Bias